THE PLEISTOCENE FORMATIONS OF SANKATY HEAD, NANTUCKET[1]

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HISTORICAL

The fossiliferous beds at Sankaty Head have been a subject of interest since first reported by Messrs. Desor and Cabot in 1849. The section has been referred to by Professor Shaler[2] as "one of the most important on the New England coast." The beds have been visited and studied by a number of well-known scientists, among whom were Professor A. Hyatt, Mr. C. H. Merriam, and Mr. Sanderson Smith, in 1875; Mr. S. H. Scudder and Mr. Richard Rathbun, a short time afterward; and, still later, Dr. F. J. H. Merrill and Dr. Arthur Hollick. While these investigators have added to the number of species reported from these beds by Messrs Desor and Cabot, they have differed somewhat in their descriptions of the beds, and in their interpretations of the phenomena presented.

The section, when first seen by Messrs. Desor and Cabot, seems, from their description, to have presented very much the appearance shown in Fig. 1, the lower clay forming twenty feet of the lower part of the section and being overlain, apparently unconformably, by the lower sands and gravels. The section at this time was freshly exposed by the cutting of the waves, but for a considerable period of years this cutting has been prevented by the northward extension of the Siasconset apron beach. The face of the bluff at Sankaty Head is now thickly covered with talus, composed of the drift material above the fossiliferous beds, and is in places overgrown with bunches of beech grass (Fig. 2).

[1] Presented to the Faculty of Pure Science in Columbia University as a Thesis for the Degree of A.M.

[2] *Bulletin No. 53*, U. S. Geological Survey, p. 30.

RECENT WORK

During the summer of 1904 the writer made extensive excavations at this point, and exposed a section from the small dunes at the foot of the bluff, to a point several feet above the fossiliferous beds. This work revealed features differing somewhat from those previously recorded, and resulted in the discovery of a number of species which have not heretofore been reported from this point. This paper presents the results of this work, and an interpretation of the phenomena observed.

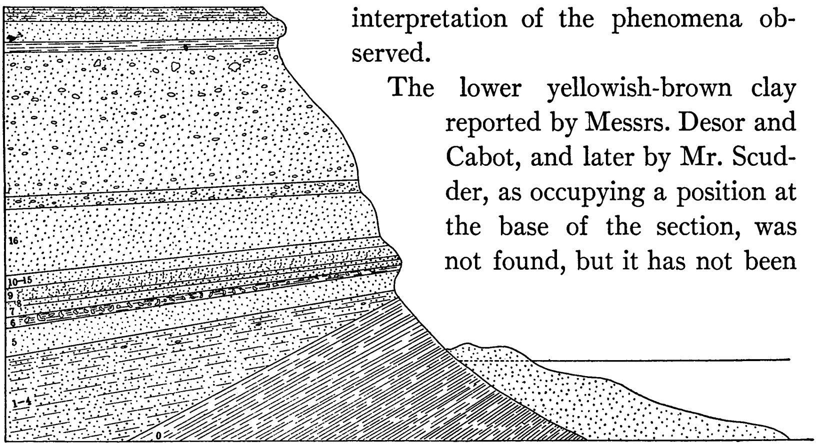

FIG. 1

The lower yellowish-brown clay reported by Messrs. Desor and Cabot, and later by Mr. Scudder, as occupying a position at the base of the section, was not found, but it has not been noticed by any observer since Mr. Scudder's investigations, and its disappearance is no doubt due to its high dip to the southwest, which, joined with the cutting back of the bluff, has caused it to sink below the level of the dune and beach sands, and thus be beyond reach of the ordinary means of excavation. Fig. 3 shows the effect of the cutting on the position of this lower clay. The dotted lines indicate the eroded portion with the clay occupying the position as first reported, while the solid lines represent the bluff approximately as it is today, with the clay hypothetically many feet beneath the dune sands, and perhaps even below sea-level.

No attempt was made to expose the section above the fossiliferous beds which constitute two-thirds or more of the bluff; but as previous investigators have found this to consist of the stratified sands and gravels normal to drift deposits, study was concentrated on the

beds from the base of the bluff to the top of the fossiliferous deposits, and especially on the latter.

LOCATIONS

These Sankaty Head deposits have often proved somewhat difficult to locate on account of the depth of talus which now covers the face of the bluff. Professor F. J. H. Merrill[1] reports them as occurring

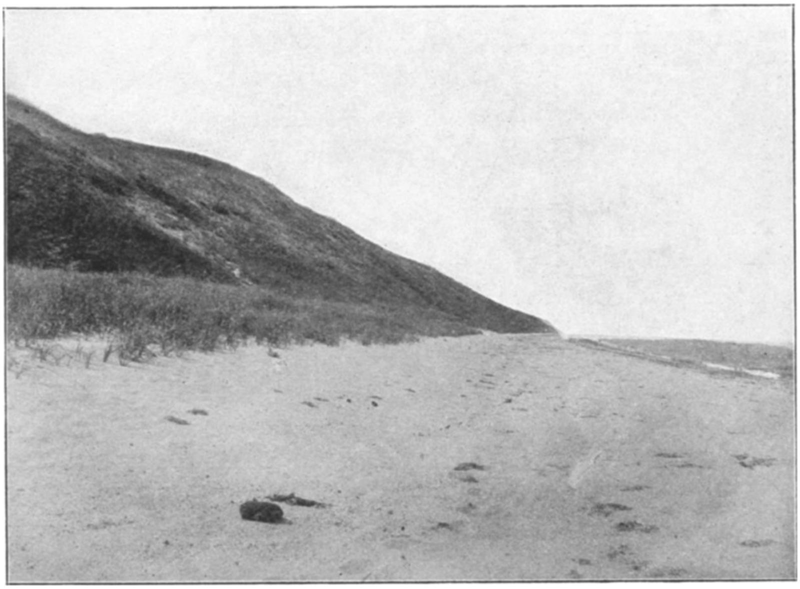

FIG. 2

"at a point about three hundred yards south of the lighthouse," and Dr. Arthur Hollick[2] refers to their position as "about a quarter of a mile south" of that structure. It is possible that they extend for some distance along the bluff, appearing at lower and lower levels toward the south, on account of the dip.

The section[3] exposed by the writer was found to be roughly 375 yards south of the lighthouse tower, measured along the top of the bluff. The section is shown in Fig. 4, and described below.

[1] *Transactions of the New York Academy of Science*, Vol. XV (1895–96), p. 11.

[2] *Ibid.*, p. 8.

[3] The fossiliferous beds were located in advance by Miss Elizabeth S. Kite.

DESCRIPTION OF BEDS

No. 1.—Light-gray sand; coarse and fine, more or less stratified and sorted, with light-colored, clayey seams ½ inch thick, which are somewhat ferruginous and hard. The coarse sand grains are rounded, the smaller are more angular and appear fresher. Small pebbles occur, mostly quartz, up to 10^{mm} (rarely 20^{mm}), which are sometimes incrusted with sand grains cemented by iron oxide.

No. 2.—Ferruginous gravel; sand grains varying in size as in the lower bed, the larger rounded, the smaller transparent and mostly angular; some rounded, and most coated with the oxide of iron; mixed with them are small grains of hornblende and magnetite; contains coarse rounded quartz and other pebbles up to 8^{cm}. In an excavation which was made through the talus 3 or 4 feet south from this point, this 3-inch bed was found to be 1 foot thick, with a base of hard, clayey sand, streaked with reddish-brown and blue clay.

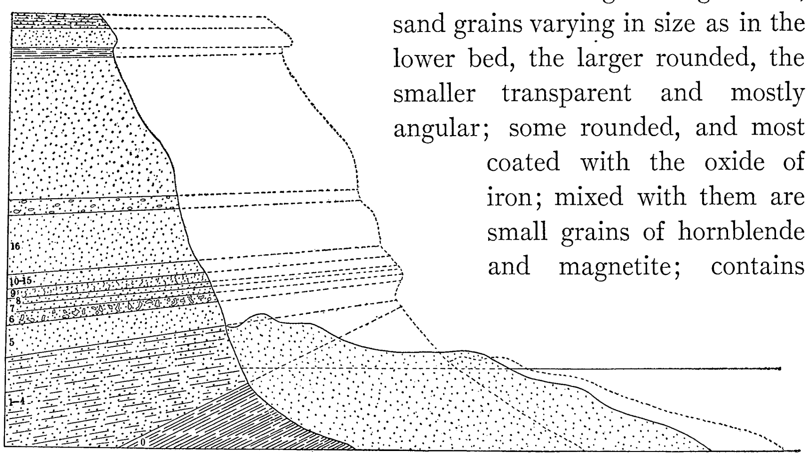

FIG. 3

No. 3.—Size of quartz grains uniform with minute grains of hornblende and magnetite. Quartz grains mostly angular, and transparent, ranging up to 3^{mm}; no pebbles; color slightly yellowish.

No. 4.—Ferruginous gravel; coarse and fine sand, and pebbles of quartz and other material up to 25^{mm}, rarely larger; sand and pebbles frequently cemented by iron oxide; pebbles and coarse sand grains well rounded; finest grains of sand angular and transparent; streaks of sand without iron ore are common throughout the bed; grains moderately worn, and quite transparent; larger grains show considerable grinding; black specks throughout, and small pebbles

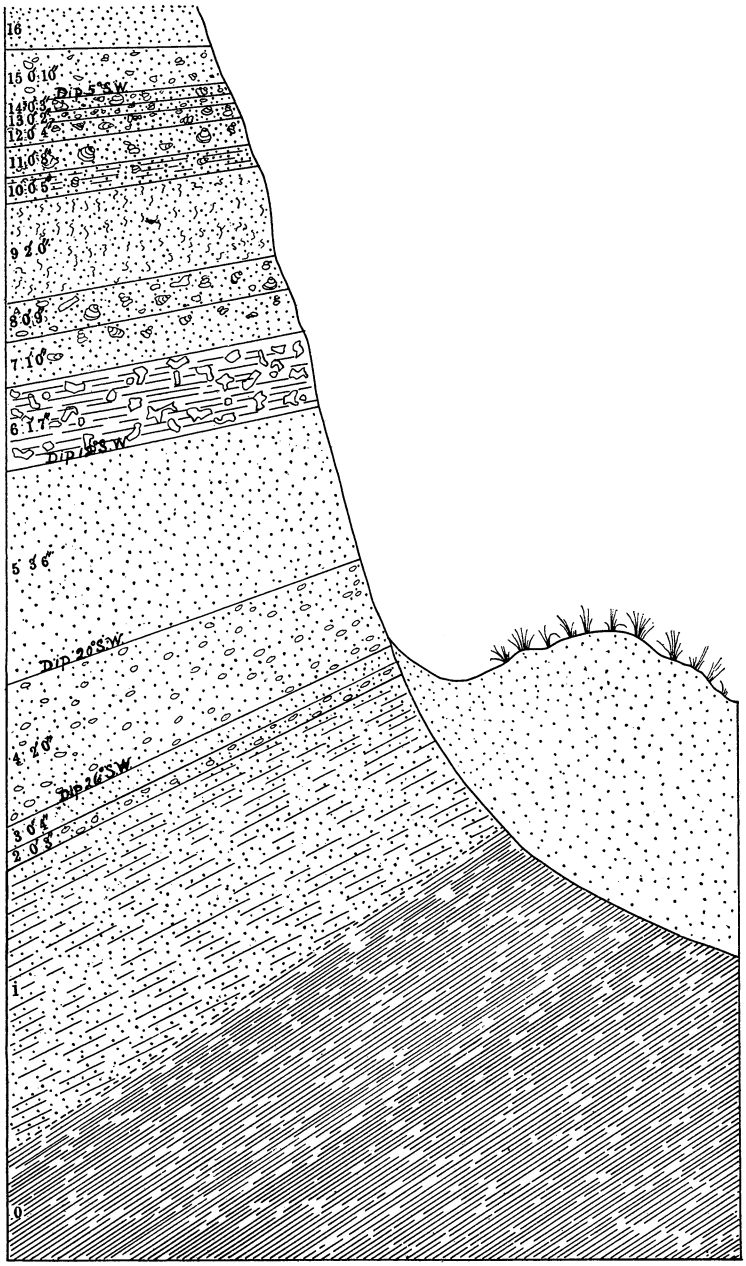
16
15 0′ 10″
Dip 5° S.W.
14 0′ 3″
13 0′ 2″
12 0′ 4″
11 0′ 8″
10 0′ 5″
9 2′ 0″
8 0′ 9″
7 1′ 0″
6 1′ 7″
5 3′ 6″
Dip 20° S.W.
4 2′ 0″
Dip 26° S.W.
3 0′ 4″
2 0′ 3″
1
0

Fig. 4

up to 15^{mm} occasionally; light-gray and pink grains, the latter garnets, the former probably epidote; material evidently derived from disintegrated granite; minute fragments of shells found?

No. 5.—Almost pure quartz sand, grains varying moderately in size, the smaller angular and transparent, the larger rounded and ground; occasional grains up to 8^{mm}; small black grains, and also dark-green grains of glauconite; occasional garnet fragments, but no pebbles; a few streaks are ferruginated; top of bed, sand fine and angular with numerous black specks. The upper surface shows giant ripple marks in places. Lignite was found in the upper part, some in fine laminæ; one stem-like piece, 20^{mm} in diameter.

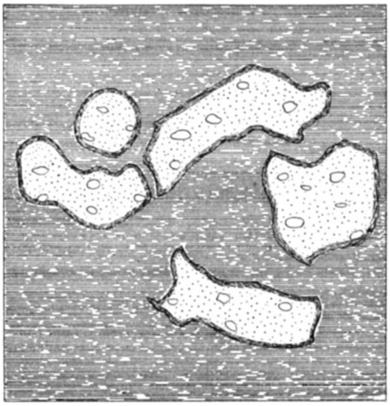

Fig. 5

No. 6.—Begins with a very fine, lutaceous sand, with mica scales and quartz grains, a rock flour with no clay odor. Higher up is blue clay, not very sticky, with faint clay odor, containing much quartz flour; pockets of ferruginous sand, which suggest decayed ferruginous concretions; one concretion found, consisting of a hard, reddish-brown shell, containing coarse ferruginous sand, and small pebbles. This structure is shown in Fig. 5.

No. 7.—Highly ferruginous quartz sand, occasional pebbles, and irregular fragments from the underlying bed. Quartz grains small, mostly rounded, and opaque by iron deposit; minute shell fragments.

No. 8.—Sand of beach type, coarse and fine, the coarse rounded and opaque, the fine angular and transparent, rounded quartz and other pebbles up to 25^{mm}. *Ostrea* extremely abundant, commonly with the valves still together, unworn and unbroken, and with barnacles still adhering to them; *Petricola pholadiformis*, with valves together and erect; *Venus mercenaria*, with valves in contact and held together by the ligament; *Mya arenaria*, with valves together and erect; *Ilyanassa*, minute *Odostomia*, and other delicate shells

occur, none showing wear. Pebbles not numerous, commonly rounded, rarely angular; no clay. This is the so-called "oyster bed."

No. 9.—Quartz sand, with ground-up shell material, and often solid masses of *Serpula dianthus;* fine material, largely fine sand, common among the talus; pebbles, except small ones, not common; no clay or glauconite noticed, but bed hardens on exposure to air. Speciments of *Arca* and *Venus*, with perfectly preserved surface markings occur, many of the latter with valves together, and ligament in place. *Solen*, *Mya*, *Cummingia*, and *Ceronia* also occur with valves together, the two former noticed in their natural upright position. A number of other species occur, and some fine shell fragments. Some shells are perforated by borings and the serpulæ sometimes occur in bunches. This bed is generally referred to as the "serpula bed."

No. 10.—Coarse quartz sand, much water-worn and rounded, many of the grains coated with iron oxide. Pebbles up to 8 ^{cm} common, generally well rounded and largely of quartz; also some fine material of lutaceous character. Shell fragments, and occasionally whole shells, mostly *Venus*, found throughout.

No. 11.—Coarse and fine sand, not well assorted. Pebbles angular or sub-angular, 5–6^{cm}, and even up to 20^{cm}; quartz-porphyry quite common. Shells entire and fragmentary, with *Ostrea* and *Venus* very abundant, the latter of the var. *antiqua*.

No. 12.—Quartz sand of varying grain, full of shell fragments and rounded pebbles, generally small, but some up to 15^{cm}; shells generally fragmentary, but many delicate ones are perfect. Large *Venus*, and well-preserved *Buccinum undatum* fairly common; shell of Mactra removed, leaving a large bunch of barnacles in the bed in the position in which they had been attached to it; bed gray, from fragments of Mytilus.

No. 13.—Reddish, highly oxidized, ferruginous sand with rounded and sub-angular pebbles up to 8 ^{cm}. This is hardly a distinct bed, but is rather a more pebbly and ferruginous layer in Nos. 12 and 14 taken as one bed.

No. 14.—Like No. 12, but more shelly; resembles an uncemented coquina, full of barnacles, in places almost entirely made up of them

(*Balanus portalus*); numerous perfect, small shells and sub-angular pebbles.

No. 15.—Mussel bed; normal beach sand, in places crowded with fragments of *Modiola*, and containing complete small shells of other genera. The mussel shell fragments are generally worn; *Balanus* fragments also common; perfect *Astarte* found, and more or less fragmentary *Lunatia heros*, and *Venus* shells; fossils like those

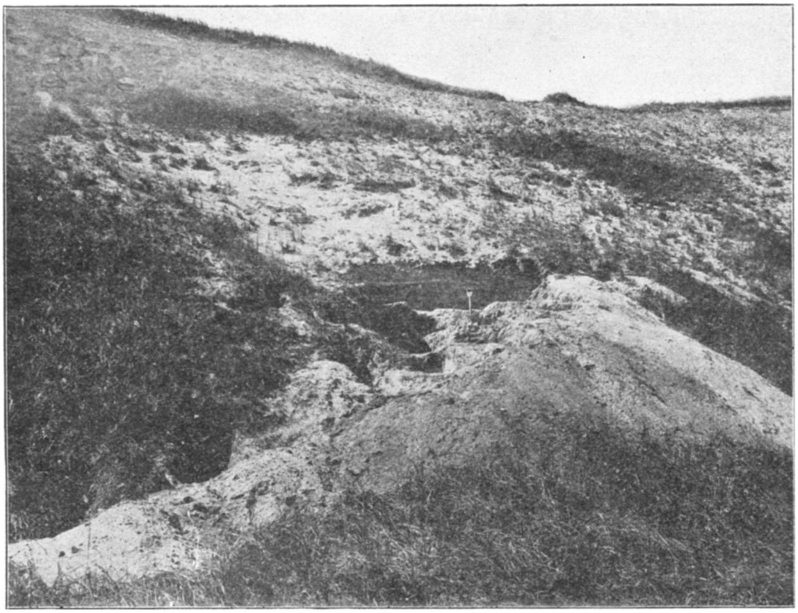

FIG. 6

found in Nos. 12, 13, 14, but not so numerous. The upper layer is marked by rounded pebbles, generally small, but occasionally 8^{cm} in diameter; pebbles sometimes occur in the mussel layer of lower part of bed. Some of the purer layers of sand are pink, rarely yellow.

No. 16.—Pure quartz sand, of varying grain, stratified and well assorted; grains all rounded and opaque, as if sand had been wind-blown before deposition; some fine streaks, almost like rock-flour, which show as very fine sand grains under microscope, and contain

mica scales; occasional small pebbles up to 6^{mm}; black specks numerous in the finer streaks; rarely a small shell fragment.

The general appearance of the section toward the latter part of the work is presented in Figs. 6 and 7. A close view of the fossiliferous beds is shown in Figs. 8 and 9. No. 8, with the serpula bed above, is shown in Fig. 8, while the beds above, including the lower part of the white drift sands, appear in Fig. 9.

FIG. 7

The upper beds will be referred to now somewhat more collectively, and their more general features described.

No. 10 seems to present some transitorial features from the serpula bed below, while Nos. 11, 12, 13, 14, and 15 have frequently been classed together as the "upper shell bed," although the last has received the special name of the "fragment bed."

In the section exposed, No. 15 seems hardly to be separated as a distinct bed from the bed below, there being no sudden change of character. The shells and shell fragments of No. 14 were found to

extend upward into this so-called "fragment bed," in the form of streaks and pockets, appearing less and less in the upper part.

The proportion of shell material to sand in No. 15, as compared with Nos. 12, 13, and 14, taken as one bed, was found to be considerably less. This would be expected in the resorting of material, the lighter and more soluble shell material being dissolved and borne away, leaving a greater proportion of sand. No. 15, then, has all

FIG. 8

the appearance of being a disturbed and partially assorted portion of the "upper shell bed."

In exposing these beds northward along the bluff, it was found that at a distance of 25 or 30 feet from the section, No. 15 pinches out, while the three beds below have become indistinguishable and their combined thickness is only 9 inches. No. 11 also appeared finer and less shelly, and had increased in thickness to 1 foot, 6 inches. The most noteworthy fact, however, and that which is responsible for the thinning out of these upper beds, is the unconformity of

No. 16, which seems to be the lowermost member of the drift deposits, or its base. So far as the writer knows, this unconformity between the fossiliferous beds and the overlying drift deposits has never before been noticed.

The general phenomena presented by these upper beds are shown in Fig. 10, in which the vertical scale is about three times the horizontal. The thinning of the fragment bed and the unconformity

FIG. 9

between it and the overlying white sands, are also shown in Fig. 9.

FOSSILS

Of the total number of species heretofore reported, only eleven were not found, and are given separately in the following list:[1]

Bryozoa
- *Membranipora tenuis Desor.*
- *M. catenularia Smett.*
- *Eschara verrucosa Esper.*
- *Celleporaria incrassata Smith* (?)

Gastropoda.
- *Scala greenlandica Perry.*
- *Eupleura caudata Say.*
- *Cerithiopsis greenii. C. B. Adams.*

[1] A *Panopens* has been reported from these beds, but its species not identified.

Pelecypoda.
Arca pexata Say.
Gouldia mactracea Linsley.
Gemma gemma Totten.

Crustacea.
Eupagarus pollicaris Say.

A complete list of the fossils found is given below. A number of species not heretofore reported from this locality were found. It was noticed also that a number of species were not found in the beds

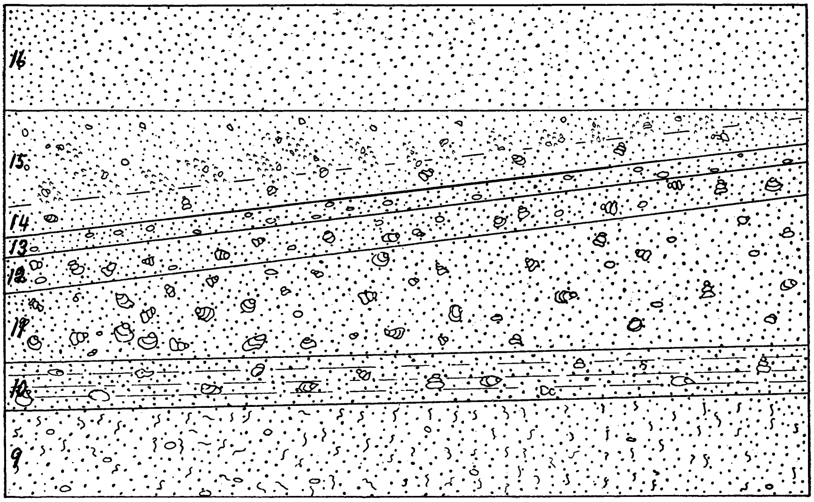

FIG. 10

in which they have been reported as occurring or are more common in some other bed. The writer is of the opinion that many fossils have formerly been collected from the talus, and referred to the wrong bed; for the irregular face of the section, covered with talus, was found at first to be very confusing, and it was not until considerable work had been done that the real nature of the beds, with their sequence and characteristic fossils, was established. Many of the fossils were collected before the work had proceeded far enough to make it possible to say with certainty what beds they came from, but, as far as possible, these will be indicated by their corresponding numbers. The species not before reported from these deposits are indicated by an asterisk.

In the table: x = occurs, a = abundant, c = common, r = rare.

	Number of Bed				
	8	9	10	11	12–15
Porifera.					
Cliona sulphurea Desor	*a*	*x*	*x*	*x*	
Echinodermata.					
Strongylocentrotus drobachiensis Müll				*x*	spines *a*
Annelida.					
Serpula dianthus Verrill		*a*	*a*		
Bryozoa.					
Hippothoa variabilis Leidy	?	*a*	*x*	?	*x*
Pelecypoda.					
Arca ponderosa Say			?		
A. transversa Say	*a*	*a*	*a*	*a*	
Venus mercenaria Linn	*a*	*a*	*x*	*x*	*x*
V. mercenaria var. antiqua Verrill		*x*	*x*	*a*	
Ostrea virginiana Lister	*a*	*c*	*a*	*a*	*a*
Anomia aculeata Gmelin					*a*
A. simplex D'Orb					*c*
Mya arenaria Linn	*c*	*c*	*c*	*c*	*x*
M. truncata Linn					few
Mactra solidissima Chemn			one		few
**Serripes laperousii* Deshayes					one
**Pecten magellanicus* Conrad					one
Ensis directus Conrad	*c*	*c*	*c*	*c*	
Corbula contracta Say			*c*		
Mytilus edulus Linn	*x*	*c*	*x*	*x*	*c*
**M. exustus* Linn	few	?			
**Modiola plicatula* Lamk	?	?	?		
M. modiolus Linn					*c*
M. hamatus Verrill	*c*	*x*	*x*		
Crenella glandula Totten					*c*
Macoma fusca Say					few
**M. fusca var. fragilis* Say					one
**M. incongrua von* Martens					? one
Cummingia tellinoides Conrad	*c*	*c*	*c*	?	
Petricola pholadiformis Linn	*r*	*r*	*r*		
**Pholas truncata* Say			one		
**Zirfaea crispata* Linn					one
Panopea arctica (Lamk.) Gould (=*Saxicava norvegica* Linn.)					frag.
Saxicava arctica Linn					*c*
Pandora gouldiana Dall					*r*
**P. crassidens* Conrad					two valves
Astarte quadrans Gould					*a*
Astarte undata Gould					*r*
A. castanea Say					*a*
**A. crebricostata* Forbes					*r*
Ceronia deaurata Turton (=*Mesodesma*)					few
C. arctata Adams					*c*

	Number of Bed				
	8	9	10	11	12–15
Venericardia (*Cyclocardia*) *borealis* Conrad....					few
V. novangliae Morse....					*c*
Thracia truncata Migh. and Adams....					few
Gastropoda.					
Odostomia impressa Say....	*a*	*x*	?	?	
O. trifida Gould....	*a*	*x*	few	few	
Turbonilla interrupta Totten....	*r*				
Ilyanassa obsoleta Say....		*x*	few		
I. trivittata Say....					*c*
Urosalpinx cinerea (Say)....	*r*	*c*	*r*	*r*	*r*
**Bittium negrum* Totten....	*r*				
Cingula (*Rissoa*) *aculeus* Gould....					*r*
**C. latior* Migh. and Adams....					one
**Cerithiopsis terebralis* Adams....					one
Skenea planorbis Forbes and Hanley....					*r*
Margarita (*Solaricella*) *obscura* Couth....					frag.
**M. undulata* Sowerby....					one
**Fasciolaria ligata* Migh. and Adams....					one
Tritonofusus stimpsoni Mörch....					*c*
**Fusus tonatus* Gould....					frag.
**Chrysodomus stonei* Pilsby....					one
Buccinum undatum Linn....					*c*
**Sipho islandicus ?* Linn....					frag.
Trophon scalariformis ? Gould....					*r*
Lunatia heros Say....					*c*
L. triseriata Say....					*c*
Neverita duplicata Say....					one
**Littorina palliata* Gould....					one
Astyris lunata Dall....				*c*	
Caecum pulchellum Stimpson....					*r*
Diodora noachina Gray....					*r*
Crucibulum striatum Say....					*r*
Crepidula fornicata Lamk....	*c*	*a*	*c*	*c*	
Crepidula convexa Say....	*c*	*c*	*c*	*x*	
C. plana Say....	*c*	*c*	*c*	?	?
Crustacea.					
Balanus crenatus Brug....					*c*
B. eburneus Gould....	*c*	*c*	*c*		
B. porcatus Da Costa....					*a*
**Eupanopeus herbsti* Milne-Edwards....		*a*			one worn claw
**Neopanope texana sayi* Smith....		*c*			
**Callinectes sapidus* Rathbun....		one claw			

It will be noticed that twenty-one species new to this locality were collected. Of these a number were identified by Dr. W. H. Dall. The crab fragments were identified by Miss Mary J. Rathbun. The identification of *Serripes laperousii* Deshayes, *Macoma incongrua* von

Martens, and *Pandora crassidens* Conrad, was a surprise, as the first two belong to the arctic fauna of the Pacific coast and, according to Dall, have not heretofore been found east of Point Barrow, while the last is common in the Miocene of Maryland, and, according to the same authority, has not previously been found above that horizon. It does not seem possible that the *Pandora* could have been derived from an older bed, as all the other species are distinctly Pleistocene; and in case the material from an older bed had been disturbed and redeposited, we should expect to find a number of associated species. Moreover, the two left valves found were entirely free from any trace of an old matrix, were no more worn than the other fossils from the same bed, and were of the same color and general appearance. It would seem, then, that *Pandora crassidens* Conrad has in some localities continued on into Pleistocene times. The two Pacific species would seem to indicate that in Pleistocene times the "Northwest Passage" was more open than at present, and perhaps also that in the interglacial period in which these beds were deposited the ice had entirely disappeared from even the northern part of the continent, so as to leave the channels along the coasts of that region free from ground ice.

A single specimen of the rare species *Chrysodomus stonei* Pilsbry was found, which was first reported and described from specimens washed ashore from supposed Pleistocene beds under the sea, off the southern coast of New Jersey. This, and the Miocene *Pandora*, are the only species yet found occurring in these beds which are now extinct.

It has been a matter of comment, that not a single *Pecten* has heretofore been found at this locality in beds furnishing in abundance such species as *Ostrea virginica*, *Venus mercenaria*, and *Mya arenaria*. In looking over a quantity of material from the "upper shell bed," a two-inch shell fragment was found which seems to be clearly identified as from near the ventral margin of a specimen of our northern species, *Pecten magellanicus* Conrad.

Modiola hamatus Verrill is mentioned in former reports as common in the "lower shell bed," and was found in association with *Mytilus exustus* Linn, from which at times it is difficult to distinguish. It is probable that the latter species has been mistaken for *Modiola*

hamatus by collectors from this locality, and all listed under the latter name.

In regard to the position in the section of *Venus mercenaria* var. *antiqua* Verrill, previous reports mention it as abundant in the "lower shell bed," but not found above this horizon. The writer found, on the contrary, that the most typical forms occurred only above the serpula bed, in No. 11, while forms less typical, and more intermediate between it and the common species, were found in the serpula bed. In this case, the name *antiqua* would be somewhat of a misnomer, as the variety would seem to represent simply a short lived mutation from the common species.

The *Astartes* as a group are very variable, presenting some puzzling differences within what may be considered a single species. Several species occur in the Sankaty deposits, and a small form which occurs very abundantly in the upper beds (over two hundred being collected), seems to have been identified in the past as *Astarte quadrans* Gould; but of the great number collected, the one which approaches nearest to *A. quadrans* of Gould seems to be identical with the variety *portlandica* of Mighels, the others differing from *A. quadrans* in a line of development far beyond even *A. portlandica.*

A number of the Sankaty Head forms are shown in Fig. 11, Nos. 6–15, while several *A. castanea* from the same locality are figured in Nos. 1–5 for comparison. The whole series of *A. quadrans* differs from *A. castanea* in their small size, excentric position of the beaks, the nearly straight anterio-dorsal margin, the absence of the broad, slightly elevated bands of growth sometimes found in *A. castanea,* and the fact that the latter has a much heavier shell, with very much higher hinge area and stronger teeth.

In the figures shown, No. 14 is almost identical with Gould's figure of *A. portlandica,* and is considered here as representing the type of that species. Most of the other forms figured, however, seem to show specific differences, being much higher and having the beaks much more excentrically situated, and should perhaps be separated as a distinct species, for which the name *sankatyensis* is proposed.

Nos. 7–12 exhibit very well this great divergence from the type of *A. portlandica,* while Nos. 6, 13, and 15 are intermediate types.

A. portlandica at the present time is more limited in its range than *A. quadrans*, and is somewhat rare.

From the fact that *A. sankatyensis* occurs only in the "upper shell bed," where it is quite common and associated with arctic species, it seems probable that it has a very northern range, or is a form which has died out, and is not represented among recent shells.

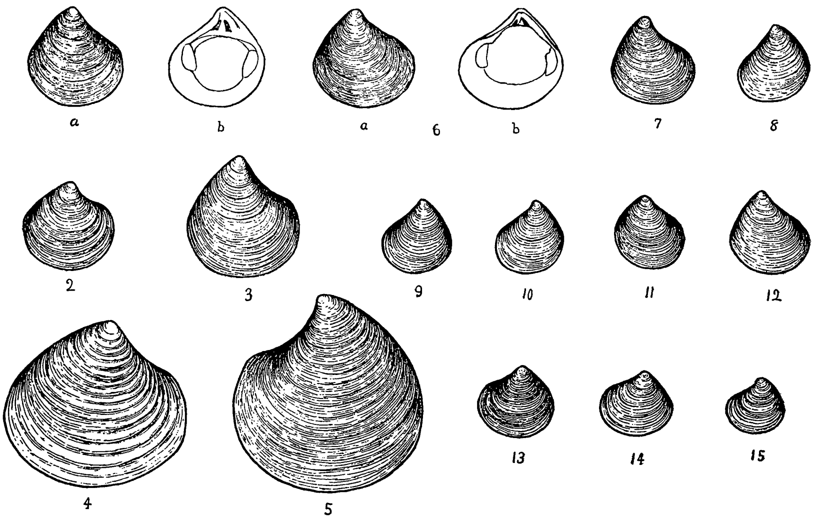

FIG. 11

INTERPRETATION

It has been thought that these fossiliferous beds at Sankaty Head were made up of old material redeposited; that the last or Wisconsin ice-sheet, moving across the sea-floor, had torn up and transported a quantity of material from old beds lying beneath the sea, and redeposited it in the present position near the ice margin. A notable case of this kind is found in the deposits containing marine fossils which are found on the flanks of Mount Snowdon in Wales, and which owe their elevated situation to the movement of the great Irish Sea glacier over the bed of that sea, and the crowding of its front with its morainal accumulations up onto the highlands of northwestern Wales.

It may be mentioned in this connection that the line of kame hills

of which Sankaty Head is the eastern extension do not represent the southern limit of the ice-sheet at this point. It was found that the ice maintained a quite stationary front some three miles farther to the south, forming the well-developed contact slope which runs in a northwesterly direction from Tom Never's Head.

The writer held the same opinion in regard to these Sankaty Head deposits at the beginning of the work, the beds at that time presenting a very confused appearance, which was found later to be due to a superficial disturbance with a mingling of talus. When the disturbed portion was finally removed, however, the beds were found to present very characteristic and constant characters. That these beds could not owe their origin to glacial action, but are normal marine deposits, seems to be certain for the following reasons: (1) Numerous delicate, perfect, and unworn shells occur. (2) Numerous bivalves, already mentioned in the description of the beds, were found in the natural position in which they lived, with both valves together, and, in the case of *Venus*, with even the ligament in place. (3) There is no mixture of faunas, as would be the case in the redeposition of material from different beds. The three lower beds contain fossils which have a distinctly southern range, and are of a shallow water type; while the upper beds contain a decidedly northern fauna, many species being characteristic of arctic seas, and of considerably deeper water. Such conditions can hardly be explained except by supposing these beds to be in their original positions.

In view of the phenomena observed, and the facts ascertained in regard to these deposits, it would seem that an attempt might be made toward an explanation of their history. The lower clay noticed by early observers is probably identical with the yellowish-brown clay found elsewhere on the island, generally more or less covered by the glacial drift. This clay is apparently an old till of pre-Wisconsin age, and which, modified by erosion, formed the land surface of hills and valleys in this region before the advance of the last ice-sheet, which buried it under a heterogeneous mass of drift. At this time shallow inlets probably occupied some of the low areas between the higher land surfaces, or lagoon-like bays were to be found at points along this old shore, protected from the open sea by bars or low barrier beaches.

The Sankaty Head deposits seem to be best accounted for as having accumulated in one of these inlets or lagoons. The lower beds were undoubtedly deposited in a shallow body of water connected with, but well protected from, the open sea. This is well shown by the prevalence of such species as *Ostrea*, *Venus*, and *Mya*, and especially numerous specimens of mud crabs, and the presence of our edible crab, *Callinectes sapidus* Rathbun, which is found today in some of the little creeks connected with the harbor on the north side of the island.

Although the total thickness of the fossiliferous beds is but 8 feet a great difference is found between the lower and upper beds, showing changes in the physical conditions. At the time of deposition of the upper beds, the waters had become much colder, probably due to the return of glacial conditions, the fossils being chiefly of the northern fauna driven southward in front of the advancing ice-sheet. The fossils, besides being more northern, and in some instances even arctic, in their range, are also of species which are generally found in somewhat deeper water.

A noticeable unconformity is found between the fossiliferous beds and the overlying 10 feet of white sand (No. 16) at the point where the section was exposed, as shown in Fig. 10. These sands are very pure, and are finely stratified and assorted, the bedding being nearly horizontal. The sand grains are mostly well-rounded and worn, and at rare intervals, minute fragments of shells occur. In fact this bed, to all appearances, seems to consist of wind-blown sand derived from dunes which have been destroyed and redeposited.

It will be noticed also from the general section, Fig. 4, that there has been a gradual decrease of dip from the lowest of the beds exposed, to the uppermost of the fossiliferous beds, above which the unconformity occurs.

The upper fossiliferous beds, with their change of fauna, the apparent unconformity above, and the overlying white sands, show changes in the physical conditions which require special explanation.

There seem to be but two hypotheses which are at all applicable to the facts, and while the phenomena can hardly be reconciled to one, it will be given first, and the points wherein it fails to satisfy the conditions will be explained. The first hypothesis may be stated as follows:

After the lower beds were deposited, and the Wisconsin ice-sheet had attained considerable extension, the land began to subside as the ice advanced, while a deeper water fauna, of arctic type, driven southward by the advancing ice, lived in the region, and its shells were imbedded in the upper beds. As the ice reached Nantucket, the pressure of its front against obstructing surfaces produced a crumpling or folding of the strata, as has been observed in other regions, such as shown in Fig. 12. This folding would account for the gradual increase of dip from the top to the bottom of the section at the point indicated by the diagonal line *AB*, representing the face of the bluff in Fig. 12. After the folding had taken place, the barrier beach brought below sea-level by the subsidence of the region, was destroyed by wave-action and redeposited as the upper white sands. As the Wisconsin ice-sheet reached and passed beyond this point, it is likely that a portion of these sands was removed; but soon deposition of glacial material began to take place, and these beds were buried under the vast amount of kame sands and gravel which form the upper part of the bluff.

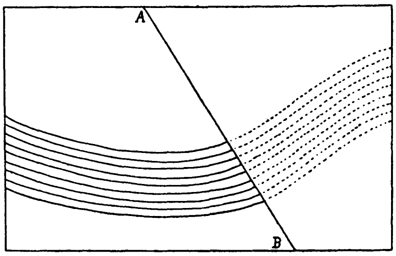

FIG. 12

This hypothesis seems to fail in the following particulars: (1) It seems improbable that the difference in dip can be accounted for in the way mentioned, because (*a*) the earliest reports on the dip of the various beds agree almost exactly with present observations, while a cutting back of the bluff, such as has taken place since the locality was first visited, should show a very different dip for the same beds as will be seen from a study of Fig. 12; and (*b*) the lateral pressure sufficient to produce this folding would be indicated by minor crumplings of the tough upper clay (No. 6), but, so far as observed, these crumplings do not occur. (2) In order to produce the folding, we must assume the ice-front to have been in the immediate vicinity, which assumption cannot be reconciled with the deposition of the upper white sands, which are of seaward origin, very pure and unmixed with any such heterogeneous material as could not fail to be present in proximity to the ice-front.

This theory, then, in its entirety, cannot be reconciled to the facts, and must be modified in some particulars.

The following hypothesis is presented as being in accord with all the phenomena observed, and probably coming nearest to the truth in an exposition of the history of these deposits:

At the beginning of this deposition, a precipitous shore probably stood to the north of the lagoon, or the lagoon itself may have been in the nature of a basin-shaped inlet, open to the south, and surrounded by steep shores of which the deeply dipping lower clay formed the portion below sea-level. A variety of material derived from this old shore by the encroaching sea before the outer bar was formed, was spread over the bottom of the basin, assuming nearly the dip of the surface upon which it was deposited, the dip becoming less and less as the basin became filled. This agrees with the coarse nature of the lower deposits, and the irregular bedding noticed. One of the lower ferruginous gravels (No. 2) was found to increase from 3 inches to 1 foot in thickness within a distance of 3 or 4 feet to the south. The dip is in the nature of a false dip, the deposits resembling very much in structure those fan-like non-marine accumulations in which the dip decreases in passing upward through the successive layers. We may consider then that the dip is an initial one, and not caused by a subsequent folding of the strata.

The lower white sands (No. 5) probably represent the washing in of some seaward material, and giant ripple marks, such as would be made by ocean waves, were found on the upper part. The lignite found in this bed is no doubt derived from seaweed and driftwood.

The lagoon or inlet now became well protected from the open sea by the development of the outer bar or barrier beach, and the upper clay of No. 6 became deposited from landward washings, on the floor of the lagoon. This now became the home of shoal water animals, as evidenced by the species which have already been enumerated. How long these conditions lasted it is of course impossible to tell, but they were brought to an end before the deposition of the upper beds. As these upper beds were formed, a subsidence of the land in this region was taking place, and no doubt connected with the advance of the huge mass of the Wisconsin ice-sheet. The water became colder, the southern fauna was driven out, and deeper-water northern, and even arctic species were present, and included in the

deposits. As the subsidence continued, the barrier beach, unable to hold its own, allowed the seas to break into the lagoon, causing a disturbance of the upper deposits, the formation of the fragment bed, and the unconformity. Finally this outer bar became destroyed, and the material of which it was composed was washed into the lagoon, forming the upper white sand (No. 16).

The next event which took place was the advance of the Wisconsin ice-sheet over and beyond this region, eventually burying the deposits under 50 feet or more of drift. This last advance of the great continental glacier may have pushed its front some distance to the south of Nantucket, during which time, and during its retreat to the position in which the Nantucket terminal moraine was formed, or during the first part of this Nantucket stage, a re-elevation of the land to its present position must have taken place.

At any rate, from evidence gathered all over the island we know that the land stood not far from its present level when the ice-front occupied the Nantucket position. There is absolutely no evidence to show that the Nantucket moraine, with its apron plain and other characters, was formed below sea-level, or at any elevation essentially different from that which it occupies at the present day.